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1. Your reference 24481

2. Pat (T 0219316.7 n this part) 19 AUG 2002

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

AB Electronic Limited, Spring Gardens, Romford, Essex RM7 9LP

Patents ADP number *(if you know it)* 844873000

If the applicant is a corporate body, give the country/state of its incorporation England

4. Title of the invention

LOCATING NON-VISIBLE OBJECTS

5. Name of your agent *(if you have one)* GALLAFENT & CO

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

9 STAPLE INN
LONDON WC1V 7QH

Patents ADP number *(if you know it)* 0000729001

6. If you are declaring priority from one or more earlier patent applications give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number

Country	Priority application number *(if you know it)*	Date of filing *(day/month/year*.

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Number of earlier application	Date of filing *(day/month/year*

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*
a) any applicant named in part 3 is not an inventor, or
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Continuation sheets of this form	
Description	11
Claim(s)	- Cf
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Priority documents	
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Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	
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11. I/We request the grant of a patent on the basis of this application.

Signature	Date
GALLAFENT & CO	19 August 2002

12. Name and daytime telephone number of person to contact in the United Kingdom — GALLAFENT & CO 020 7242 3094

LOCATING NON-VISIBLE OBJECTS

This invention relates to locating non-visible objects, particularly though not exclusively for the purpose of identifying the position of a non-visible object prior to carrying out a mechanical processing step in the vicinity of the object so located.

There are many situations where it is desired to locate something accurately, although the item in question is not visible. A simple example is to locate the position of a load-bearing member in a partition wall made of a wooden frame to either side of which sheets of plasterboard are attached. If it is desired to fix something to the wall, e.g. using a hook, it is necessary to ensure that the hook, e.g. screwed into the wall, goes into part of the timber support rather than into the plasterboard, from which it will be easily removed when a load is applied because plasterboard is not particularly strong. Conventional methods, such as tapping the wall with a knuckle to determine the location of the supporting wooden frame members do not give particularly accurate results and require skill. Making a pilot hole through the plasterboard and inserting a piece of bent wire through it into the cavity likewise is not easy to carry out simply, and although location, e.g. using a small magnet, of the usually iron

nails which hold the plasterboard to the wooden structure can be employed, again the results tend to be rather inaccurate, although this last approach does have the advantage of avoiding trying to insert a hook where there is already a nail underneath.

Similar problems can arise in many other situations, some being particularly critical for manufacture. For example, in the manufacture of aircraft, a widely used technique is the application of a metal plate or skin to an underlying frame, for example made of ribs or spars. In order to ensure a firm connection between the skin and the rib or spar, a technique commonly employed is that of fastening the two together, e.g. with a rivet or special fastener. In order to do this, apertures in the skin and the rib or spar need to coincide and this needs to be particularly accurate since if there is inaccuracy, rivetting may be rendered more difficult, or even impossible and inadequately-fitting or mis-applied rivets can become loosened when the aircraft is in service leading to potentially catastrophic failure. Accordingly, the requirements for accurate matching of the hole in the skin with the hole in the rib or spar are very stringent and the penalty for inadequate accuracy may well be the failure of the finished assembly to meet the required rigorous safety standards, leading to the entire assembly having to be recycled. Although if the rib or spar has pre-formed holes, it is notionally possible to use those holes as guides for manufacturing holes in an applied skin, this is usually awkward and sometimes practically impossible for reasons of space. Additionally, drilling a hole through the skin from inside does not always provide adequately accurate alignment of the hole in the skin, i.e. it will not be accurately perpendicular to the surface of the skin. Working from the outside, however, i.e. working with the skin between the operator and the spar or rib means that the positions of the holes cannot be seen.

The object of the present invention is to seek to provide apparatus enabling the detection of a non-visible object, for example of the types indicated above, quickly and accurately. It should be noted that the term "object" as

used herein is intended to cover a very wide variety of possibilities, including, in particular, a hole.

The concept underlying the invention is the realisation that a non-visible object, i.e. one which cannot be seen because it lies behind something opaque, differs in its physical properties from its surroundings. The physical property may be selected from a wide range of possibilities, but all physical properties relevant for the purposes of this invention share the feature that they are detectable remotely by the use of suitable sensors. Typical properties include magnetism, capacitance and inductance, all of which can be sensed using suitable sensor technology from a distance via non-metallic or non-ferromagnetic material.

Accordingly broadly to the present invention, there is provided a method of locating an object lying behind an opaque surface rendering the object non-visible which comprises applying to the surface an array of sensors adapted to sense a parameter which varies with the variation in distance between the sensor and the object, the array of sensors being associated geometrically with means identifying a datum point, such that the datum point and the array of sensors are fixed positionally one relative to the other, actuating the sensors to determine the value of a measurement of the physical property for at least the majority of the sensors, analysing the sensor responses to determine the displacement between the object and the datum point, and moving the array and datum point to a position in which the displacement is a minimum.

Using such an approach, the location of the object behind the opaque surface can be rapidly and easily determined and when the displacement is a minimum, the datum point is then located adjacent the surface at that point of the surface immediately and centrally overlying the object in question. The position of the datum point can then be marked on the surface if desired, or the datum point may be defined, for example, by means of a guide tube which, with the array fixed in position, can then be

used to guide, e.g. a drill to make a hole in the opaque surface precisely located relative to the non-visible object.

The present invention accordingly also provides apparatus for locating non-visible objects positioned behind an opaque surface, which apparatus comprises a base member adapted to be placed on or against the surface, means in the base member defining a datum point, an array of sensors located around the datum point and adapted to sense a physical parameter, and means for collecting and analysing outputs from the sensors to provide an indication of the variation of the parameter being sensed relative to the extent of the base member.

Preferably the base member is adapted to be moved across the surface to enable the datum point to be aligned with the object. Preferably the means for analysing includes a visual display means adapted to indicate the location of the object relative to the array of sensors, and accordingly to indicate when the array is positioned with the datum point associated therewith located closest to the non-visible object.

The present invention is particularly valuable in the technical area of locating holes, particularly, though not exclusively, in the technical field mentioned above, i.e. in fitting an opaque metal skin on to underlying supporting members in aircraft construction. While it is theoretically possible to detect the presence of a hole in an underlying spar or strut because the physical properties of the hole differ from that of the surrounding material defining the hole, appropriate sensors can be expensive and the usually necessary alignment and calibration of an array of them can be complex. In this particular application of the method of the present invention, however, a simple and highly effective approach is to put something with easily detectable different physical properties from the surrounding material defining the hole in the hole itself, and using appropriate matched sensors to define the position of the item temporarily placed in the hole. This is found to work well using a small cylindrical

magnet, one end of which is fitted in the hole in question and using an array of Hall effect sensors to detect the magnetic field from the magnet. Conventional alloys used for aircraft construction are predominantly aluminium alloys which are non-ferromagnetic, so the use of a small cylindrical magnet enables very clear and defined signals to be obtained from an array of Hall effect sensors, even if the skin is thick, e.g. up to 70 mm thick. Other materials may be even thicker - e.g. carbon fibre composites 70 mm or more thick.

The array of sensors is customarily a symmetrical array about the datum point. The number and positioning of the sensors in the array may be varied depending upon the degree of precision required as well as on the type of sensor. A particularly preferred approach is to use a cruciform array of sensors with a plurality of sensors located spaced along the arms of a notional cross, the datum point then corresponding to the centre point of the intersection between those arms, ass this needs only relatively straightforward data processing of the sensor signals. However, in appropriate circumstances, the array may be more complex, e.g. 16 sensors x 16 sensors arranged in a square grid. The processing of the data set from the sensors may then be more complex, but the accuracy of positional detection may be greater.

The visual display providing an indication of the location of the object relative to the location of the array is preferably compact and easy to understand. A particularly preferred form of display is that of a computer-driven flat display screen on which are represented in appropriate symbolic fashion the location of the object and the location of the datum point. By moving the array and datum point, the graphic representations on the screen may be made to coincide. The display screen may, for example, form part of a conventional laptop computer, or a hand-held computing device, often referred to as a PDA. In either case, by combining appropriate programming and interface electronics, the signals from the individual sensors in the array may be processed using known techniques to produce

the indication on screen. By appropriate programming, sophisticated features may be introduced rendering the apparatus easier to use, for example automatic re-scaling of the display as the datum point and object approach coincidence as the array is moved. When the array is first placed on or against the opaque surface, the location of the object may be displayed relative to the location of the entire array, and as the array is moved to bring datum point and object into close alignment, so the display may be reset automatically to concentrate only on the narrow area around the datum point, even though the signals from the entire array may still be used as desired to calculate the relative positions of array and object.

Once coincidence has been achieved by moving the array relative to the object, it is desirable to fix the two temporarily in position one relative to the other in order to allow the datum point to be used, e.g. for the application of an accurate marking on the surface corresponding to the location of the non-visible object thereunder, or for acting as a positioning jig to enable a mechanical process to be carried out on the opaque surface, for example making a small identifying dent in it to indicate a position for assistance in subsequent processing, or, for example, drilling a hole at the position so identified. For either purpose, the apparatus preferably includes means for temporarily fixing the array in a position on the opaque surface, for example by attaching it via actuatable vacuum pads thereto.

The use of vacuum pads is particularly recommended in cases where the opaque surface is not horizontal, a state of affairs often encountered in the assembly of e.g. large aircraft or aircraft components. In such a case, the base carrying the array of sensors is preferably equipped with vacuum pads which can be subjected to reduced pressure at two discrete levels, one level providing a sufficient holding force to attach the base member of the array to the surface sufficiently loosely that it can still be moved around relative thereto, and a stronger holding level at which the base member holding the array of sensors is essentially firmly clamped in fixed position against the opaque surface. Vacuum fixation (or other fixing means) may

also be conveniently used to locate a display unit, particularly where the display unit is PDA, on a portion of the opaque surface close to the portion under which the object is located. Operating in this way is possible rapidly to locate, e.g. holes in a spar underneath an opaque wing skin to an adequate degree of precision.

Alternatively, the application and fixation of the base may be achieved by mounting it on a robot arm, and so arranging the control of the robot that the base may be moved to the area of interest, sensing applied to locate the hole and the base then moved to align it as desired, whereafter it may then be held firmly in place by the robot while other actions are effected, e.g. drilling a hole through the skin.

The accuracy of performance of apparatus as just described is clearly susceptible to deterioration on account of sensor ageing. This problem can be alleviated by providing, for use with the sensor array, some form of standard template of known responsiveness and having means to enable the base member carrying the sensor array to be accurately and repeatable coordinated to the template. Using appropriate software programming, the individual sensor responses can be interrogated when the array is positioned on the template and the actual responses compared with those which should theoretically be produced, or which have been produced using the same set-up but in the past, with the current values. The programming of the data capture and analysis software may be such as to enable automatic corrections to be applied to compensate for sensor drift or loss of sensitivity.

As noted above, apparatus according to the invention is particularly useful when the sensors are Hall effect sensors and the object, the position of which is to be detected, is magnetic, or can be rendered magnetic. However, it will be clear to the reader that a wide variety of analogous methods and apparatus may be respectively carried out and constructed using the inventive principles explained above. For example, the location of

support brackets behind a plastics car bumper or body panel may be determined to enable the accurate pointing of an ultrasonic welding head to fuse the bumper or panel on to the bracket. Also the location studs or other components embedded in plastics mouldings may be detected, either for product checking or for fixing purposes. These may use capacitative sensor arrays.

By way of further explanation of the invention, and by way of illustrating how it can be put into practical use, reference is made to the accompanying drawings, in which:

Figure 1 is a diagrammatic illustration of a section through a sensor array located adjacent an opaque metallic skin in turn located adjacent a pre-drilled spar; and

Figure 2 is a diagrammatic perspective view showing apparatus in accordance with the invention in use.

Referring to Figure 1, this shows in extremely diagrammatic form the present invention applied to the detection of holes in a spar on the far side of a metal cladding sheet. For the sake of simplicity, only one hole is shown in the flat portion of a spar generally indicated at 1, the hole being denoted 2. As shown, a flat plate 3 which is to be attached to the spar is placed against it.

In order to enable detection of the position of the hole, a magnet 4 set in a suitable mounting is press fitted into the hole 2 from below as shown in Figure 1.

Located on top of plate 3 as shown in Figure 1 is a sensor array generally indicated at 10. This array consists of a base member having a generally flat undersurface in which is set a cruciform array of sixteen Hall effect sensors 12. As seen in the drawing, eight of the sensors 12 are seen

spaced to either side of a central sensor 12. The eight are aligned in a row and the central sensor 12 is the end sensor of the row of the remaining eight sensors set at right angles to the first row. Reference number 14 denotes the wall of a cylindrical aperture in the middle of the array.

As will be appreciated, the end of the magnet assembly 4 inserted into hole 2 is the centre location of a generally symmetric magnetic field having its maximum located in terms of the upper surface of plate 3 at the point on that upper surface which is precisely aligned with the axis of hole 2. As the Hall sensors are more remote from that point, so the magnetic field strength diminishes.

The Hall sensors are connected via a suitable signal-carrying cable 16 to an evaluation electronics, for example in the form of a laptop computer or PDA.

It will readily be appreciated that if the array 10 is located as shown in Figure 1 with the hole 14 located coaxially with the hole 2, then the magnetic field strength will be greatest and of equal value at the positions of the Hall sensors radially closest to aperture 14, with the field strength detected by each of the sensors more remote from aperture 14 and being lowest at the outermost ones.

If the array 10 is shifted from its position in Figure 1, the field strengths will vary at the individual sensors and the signals from them can be appropriately analysed to work out how far the axis of aperture 14 then deviates from the axis of hole 2. By moving assembly 10 to minimise that deviation, the aperture 14 may be aligned with hole 2 essentially seen from above as shown in Figure 1. Aperture 14 may then, for example, have a drilling guide inserted into it, or, for example, a marking implement of some type so as to identify that piece of the upper surface of plate 3 which lies on the axis of hole 2.

Figure 2 shows diagrammatically a practical embodiment of the application, though still with reference to the fixing of a skin to a pre-drilled spar. Like reference numerals are used in Figure 2 for like parts and although Figure 2 is shown with the skin 3 generally horizontal, it should be appreciated that, very often, the plane of skin 3 will not be horizontal.

For this reason, the array 10 is provided with suction pads 20 which may be subjected to suction via a line 22. The suction may be applied at two levels and the construction of the underside of the suction pads 20 is such that, when applied at one level, the pads 20 serve to hold the assembly 10 against sheet 3, but not so firmly that it cannot be moved around, e.g. by hand. At the second suction level, suction pads 20 act to pull the assembly 10 firmly against sheet 3, so rendering it essentially fixed in position. Accurate alignment of the assembly 10 against the skin 3 is ensured by providing three feet on the underside of assembly 10 (not shown in the drawing) which, when the higher level of suction is applied, all seat finally against the surface of the skin 3. Accurate positioning of assembly 10 against skin 3 is important since, for example, once assembly 10 has been put into the correct position with aperture 14 registered with one of the holes 2 in the spar 1, a drilling guide (not shown) may be inserted into aperture 14 and a drill then passed through the drilling guide to drill a hole in sheet 3 which will then be accurately aligned with one of the holes 2 in the spar 1. Thereafter, the high suction is released entire assembly may be moved out of the way and a rivet or other fastening of conventional type inserted into the registered apertures in sheet 3 and spar 1 to attach the two together. This procedure may be repeated until all of the necessary fixture connections are made.

As shown in Figure 2, connected to flexible signal lead 16 is a PDA indicated generally at 24. The programming of the PDA is such as to produce on its screen a display consisting of a set of concentric circles 26 and a representation of a cross 28. The position of cross 28 varies as the array 10 is moved relative to the underlying aperture 2 with magnet 4 in it.

When aperture 14 is accurately registered with the hole 2 in which magnet 4 is inserted, the cross 28 is located precisely centred in the middle of the innermost circle 26.

If desired, PDA 24 may also be attached to the sheet 3 by means of an appropriate vacuum pad located on its underside.

Since the electronics in PDA 24 is capable of detecting when such alignment occurs within appropriate tolerances, it is feasible, if desired, to have the PDA emit a signal via an appropriate user port which controls a controller applying the relevant level of reduced pressure via lead 22, so enabling automatic locking in place of array 10 as soon as aperture 14 is aligned with a hole 2. This can lead to very efficient operation which is desirable when, for example, in the case of an aircraft wing, the spar 1 may be several metres or more long and the number of holes 2 to be detected and corresponding holes drilled through the skin 3 runs to many tens, or even a few hundred.

The detailed physical construction of array 10 may be varied widely, for example by using other forms of array of Hall effect sensors than that shown. It is, of course, important to ensure that the entire unit of the Hall sensors themselves, the suction pads, and the base or frame carrying both should be made of non-ferromagnetic material, for example naval quality brass.

ABSTRACT

LOCATING NON-VISIBLE OBJECTS

Non-visible objects which differ in their physical properties from their surroundings may be detected by a suitable array of physical sensors which can be moved relative to the object in question. By analysing the signals from the plurality of the sensors in the array, the position of the object can be deduced relative to the array and the array moved to enable a datum point thereon to be aligned with the non-visible object. The system is of particular value in locating apertures (2) in wing spars (1) when attempting to fix cladding sheets (3) on to them where it is important to be able to locate the correct point at which to drill a hole through the cladding sheet (3) to coincide with the hole (2) in the spar. By putting a magnet (4) in the hole to identify the hole magnetically and using an array of Hall sensors (12) in a base with an aperture (14), it is possible to shift the array (10) so that the aperture (14) is precisely aligned with the non-visible hole (2).

Fig. 1

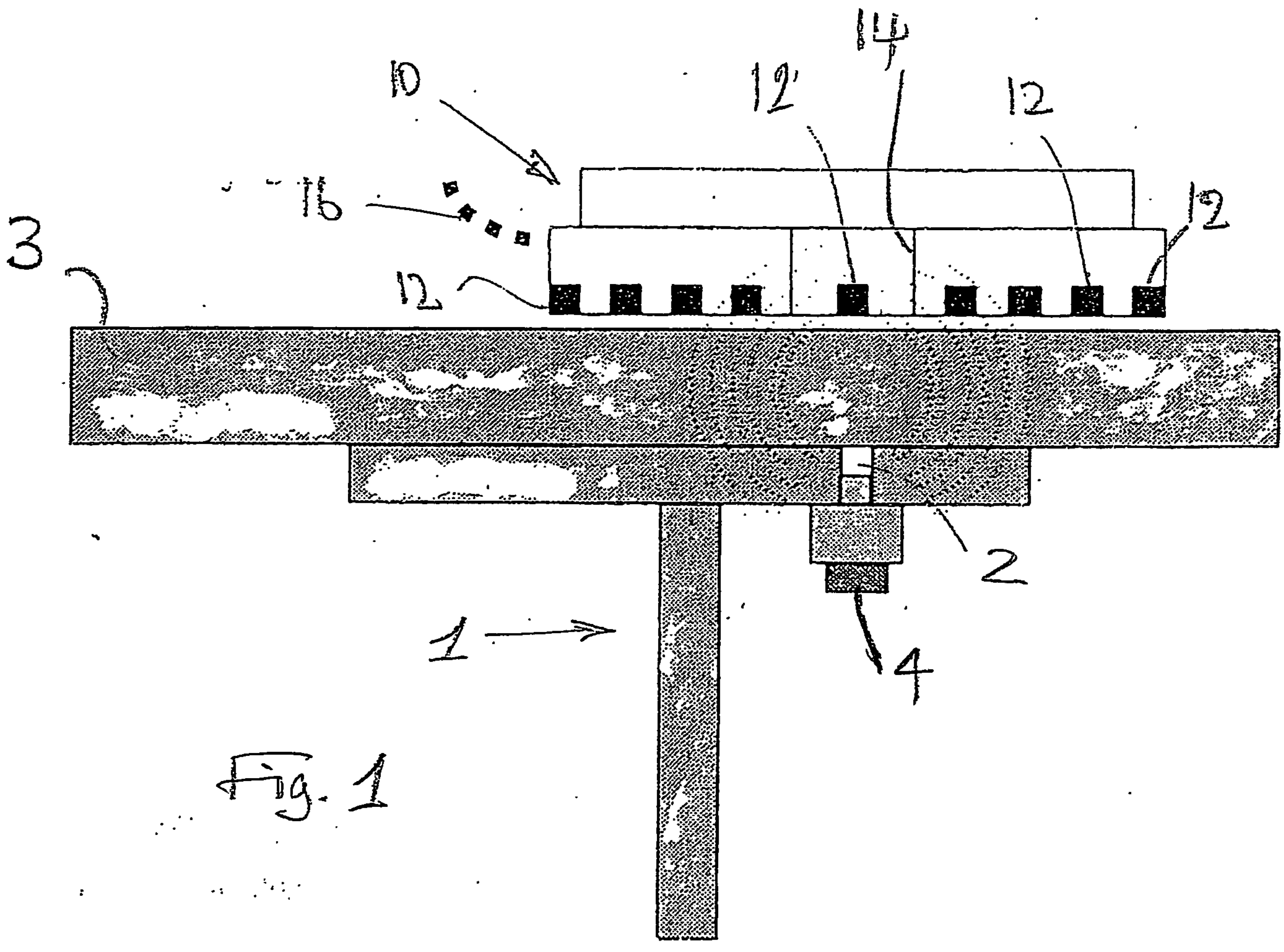

Fig. 1

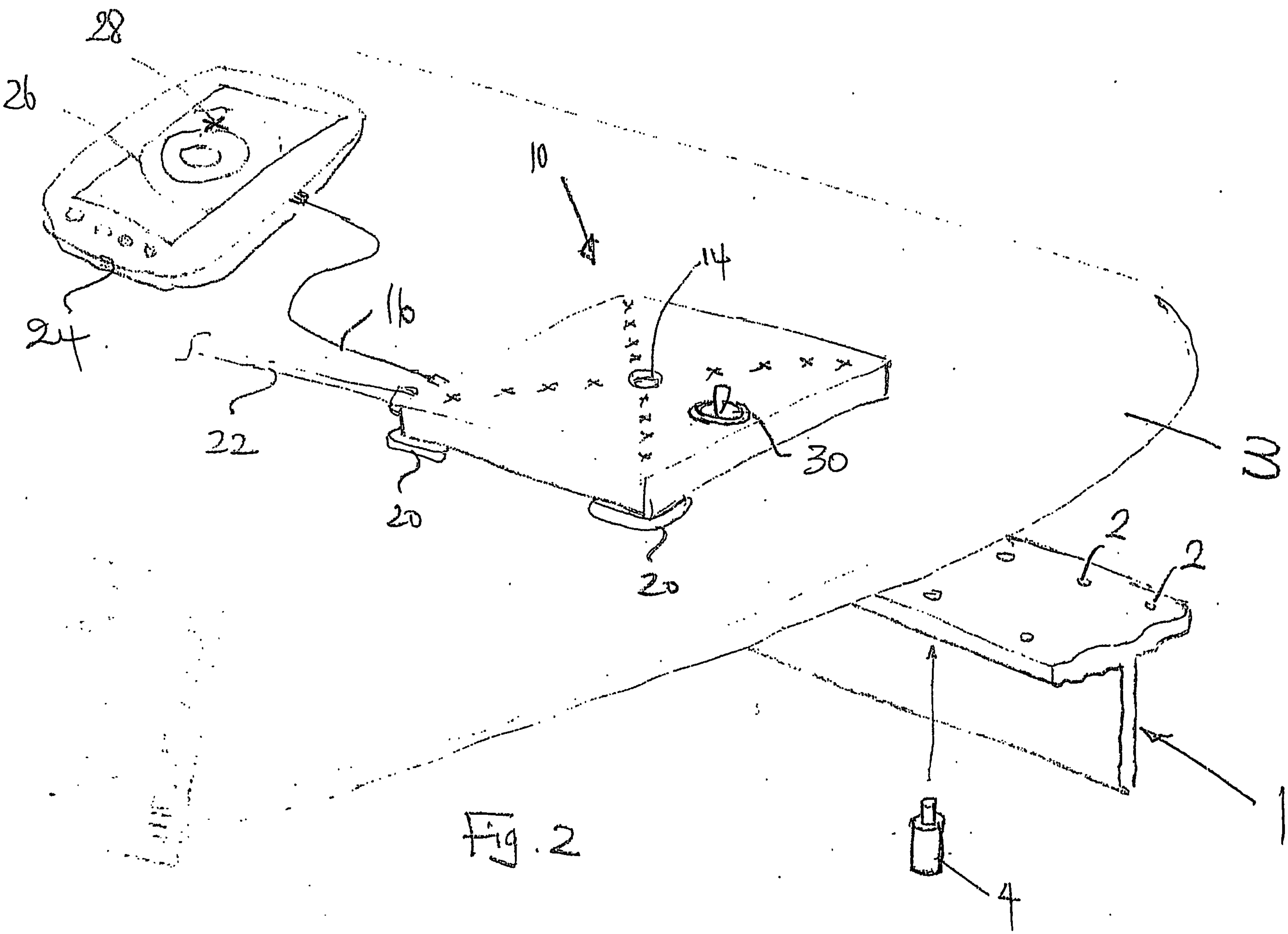

Fig. 2